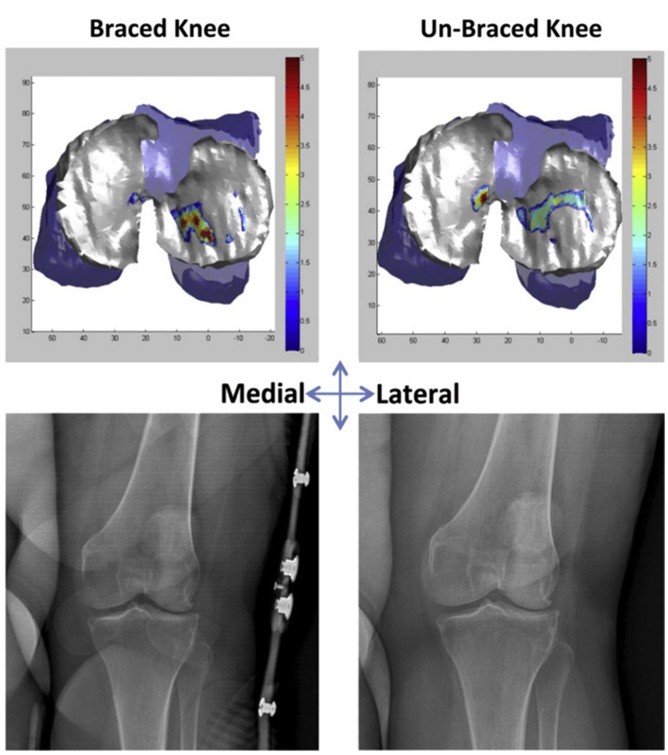
and without an UnloaderOne knee brace applied (one knee per participant). Sagittal 3 Tesla magnetic resonance imaging (MRI) was performed using a 3D water-excitation dual echo steady state (WE-DESS) sequence. The bone and cartilage boundaries were segmented from MRI to generate knee-specific 3D point clouds. The smoothed 3D bone surface models were then registered to corresponding bone edges on weight bearing 15° flexed knee radiographs, using a semi-automated computer algorithm. The 3D cartilage surface models were then added to each bone model, and discrete element analysis (DEA) methods were used to estimate articular contact stress distributions (Figure). Computational simulation, using DEA provided estimates of compartment-specific mean and maximum contact stress with and without the brace applied. Paired t-tests were used to assess the differences in contact stress comparing the braced and unbraced conditions in each participant.

Results: There were 6 men and 9 women enrolled. The mean±SD age was 56.1±6.4 years and BMI was 28.4±4.5 kg/m^2. Twelve of 15 participants were fit with braces set to unload the medial compartment and 3 were fit with braces set to unload the lateral compartment. The average (95% CI) change in mean contact stress in the compartment of interest was 0.16 (-0.41, 0.73) MPa ($p>0.55$). The average (95% CI) change in maximum contact stress in the compartment of interest was 0.34 (-1.44, 2.13) MPa ($p>0.68$). The percentages of change in mean and maximum contact stress in the compartment of interest were 2% (-25%, 21%) and 2% (-37%, 42%), respectively ($p>0.85$ for both). Overall, estimates of contact stress in the compartment targeted for load reduction increased in 8 knees and decreased in 7 knees. Confirmatory analyses were conducted in the following subsets: 1) knees without bone-on-bone contact and 2) knees in which the brace was considered an excellent fit. In each of these sub-groups, estimates of contact stress in the compartment targeted for load reduction increased in 4 knees and decreased in 4 knees, and there were not statistically significant changes in the mean or maximum contact stress distributions.

Conclusions: This is the first study of the effects of frontal plane realignment braces on in vivo articular contact stress in native human knees. Using advanced estimates of articular contact stress, changes in compartmental contact stress distributions were not detected with use of the off-the-shelf brace tested. These findings indicate that either the brace that was studied was not effective at redistributing tibiofemoral contact stress, or that participant factors led to a mixture of responders and non-responders to this therapy. Further research is necessary to determine whether customized frontal plane braces are effective in redistributing compartmental articular contact stress.



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DYNAMIC FINITE ELEMENT MODELING OF KNEE MECHANICS

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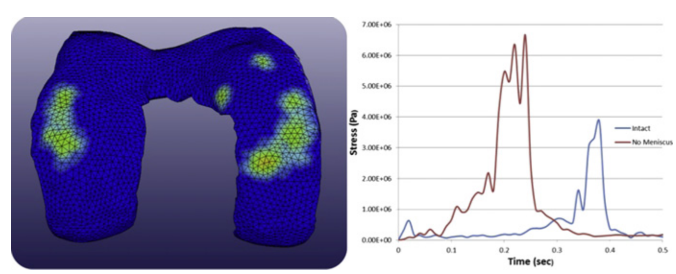
Purpose: It is widely accepted that alterations in the mechanical environment within the knee is a leading cause of knee osteoarthritis (OA). However, a significant unfulfilled technological challenge in musculoskeletal biomechanics and OA research has been determining the dynamic mechanical environment of the cartilage (and other components) resulting from routine and non-routine physical movements. There are two methods of investigating musculoskeletal joint mechanics that have been used to date: 1) forward and inverse multi-body dynamic simulations of human movement and 2) detailed quasi-static finite element modeling of individual joints. While the overwhelming majority of work has been focused on biomechanical multibody dynamics modeling, these types of simulations do not allow for the detailed continuum level analysis of the mechanical environment of the cartilage and other knee joint structures (meniscus, ligaments, and underlying bone) within the knee during physical activities. This is a critical gap that is required to understand the relationship between functional or injurious loading of the knee and cartilage degradation. The objective of this investigation was to develop a detailed neuromuscularly activated dynamic finite element model of the human lower body in order to simultaneously determine the dynamic muscle forces, joint kinematics, contact forces, and detailed (e.g., continuum) stresses and strains within the knee during controlled and muscle actuated movements.

Methods: A finite element model of the lower body was developed using individual digitized anatomic surface models. Contact conditions were defined at the knee joint between the femoral cartilage, tibial cartilage, menisci, and patella cartilage to constrain articular joint motion based on anatomic geometry. All the ligaments of the knee were modeled as non-linear one-dimensional springs; the femoral cartilage, tibial cartilage, menisci were modeled as linear elastic materials using published material properties. Fifty-nine muscles of the lower limbs were modeled using active contraction Hill-type muscle springs using published insertion points and muscle parameters. The model was configured to simulate a seated leg extension by activating the quadriceps. We used a parameter optimization method to directly optimize muscle activation parameters within the dynamic FE model (LS-DYNA (v. 971, LSTC, Livermore, CA) based on a physiologic cost function. Once optimal muscle activations were determined, we investigated the changes in the mechanical environment within the knee due to removal of the meniscus.

Results: The final optimal muscle activations required to perform a leg extension resulted in a smooth, controlled dynamic movement. The dynamic stresses in the femoral cartilage during the leg extension were significantly higher (with the peak stress also occurring significantly earlier in the motion) in the knee without a meniscus compared to the intact knee (Figure 1).



Conclusions: The dynamic muscle forces, joint kinematics, contact forces, and detailed (e.g., continuum) stresses and strains within the knee (cartilage, meniscus, ligaments, and bone) were simultaneously determined for a neuromuscularly controlled seated leg extension with a weight of 30 lbs. added to the ankle. This methodology was used to investigate how structural and material alterations in this complex environment due to removal of the meniscus altered the mechanical environment within the knee. Removal of the meniscus significantly affected not only the peak cartilage stresses, but significantly altered the time course of those stresses during a dynamic knee extension. Future studies will focus on the how effects such as anatomical differences, obesity, and sarcopenia (each of which are risk factors for knee OA) potentially affect the detailed dynamic mechanics of each component of the knee joint.

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MECHANICAL PROPERTIES OF BABOON CARTILAGE DEMONSTRATE A SIMILAR DECLINE WITH AGE AS HUMAN CARTILAGE

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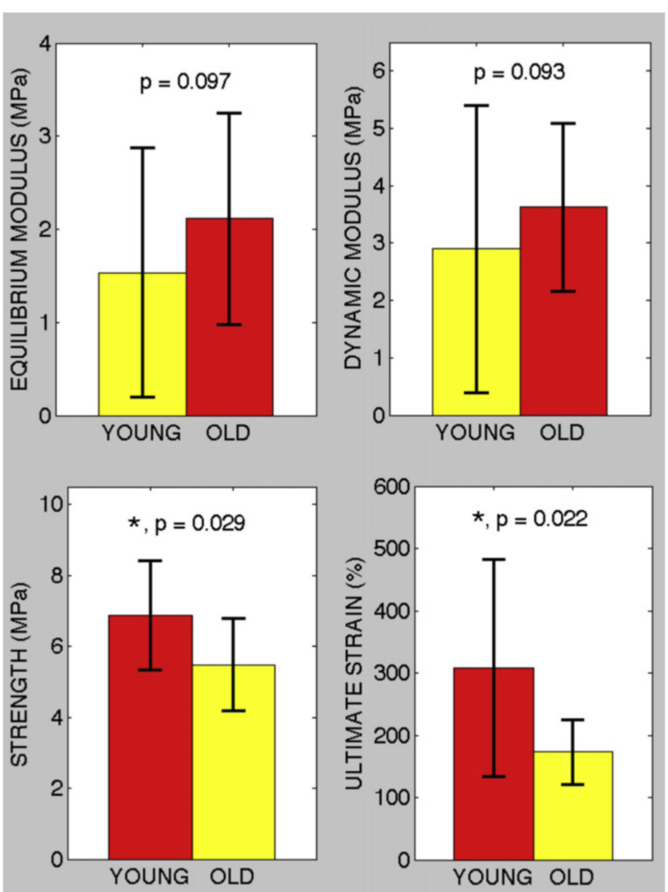
Purpose: Osteoarthritis (OA) is the most common form of arthritis and the major cause of activity limitation and physical disability in older people. It is widely believed that OA results from the local mechanical environment of the joint and, particularly, the cartilage, in combination with systemic susceptibility to the disease. Preliminary study of knee OA in the baboon demonstrated that knee OA occurs commonly and naturally in male and female adults and the frequency of OA in older baboons is comparable to that in older humans. The objectives of this study were to evaluate whether the mechanical properties of baboon cartilage follow similar trends with age and sex as humans, and whether the presence of affected cartilage leads to mechanical property degradation.

Methods: Sample groups were established based on combinations of age (i.e. young/old), sex (i.e. male/female), and overall femur OA status (i.e. affected/unaffected) (target $n = 5$ in each group combination). Baboons were categorized as young for age > 15 years (developmentally equivalent to 45 human years) and old for age > 22 years (developmentally equivalent to 66 human years). Overall femoral condyle OA status was determined based on established cartilage grading methods. Knee cartilage was obtained from the medial portion of the distal condyle of baboon right femurs collected at routine necropsy at the Southwest National Primate Research Center/Texas Biomedical Research Institute. Dogbone-shaped tensile specimens were prepared with the gage region oriented perpendicularly with the primary direction of collagen orientation. Specimens were kept hydrated and loaded under displacement control to 10% and 20% strain at 0.25%/sec and allowed to stress relax until equilibrium was reached, and finally loaded to failure. Equilibrium tensile modulus, dynamic tensile modulus, peak stress (strength) and strain at the point of peak stress were determined from the normalized load-displacement data. Wilcoxon rank sum tests were used to evaluate statistical significance of group differences.



Results: There were significant decreases between the young and old specimens in strength and strain at peak stress (Figure 1). Equilibrium modulus and dynamic modulus demonstrated increased stiffness for cartilage specimens from old animals; however, these differences were not statistically significant (Figure 1). Differences in cartilage properties based on sex and OA status were not statistically significant ($p > 0.187$ in all cases and $p > 0.259$ in all cases, respectively).

Conclusions: Despite the small sample sizes used in this study, statistical differences were demonstrated between cartilage specimens obtained from young and old baboons in both strength and the strain at peak stress. It is well documented that cartilage mechanical properties demonstrate decline with age in humans and our demonstration that baboon cartilage properties behave in a similar fashion further justifies the use of the baboon as a model for the human osteoarthritic condition, in addition to the physiological similarities between species. We expect that results obtained from larger sample sizes of cartilage specimens obtained from locations throughout the baboon knee joint will further elucidate the effects of age, sex, and OA involvement on the functional behavior of cartilage.

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KNEE JOINT LOADING RATE DURING WALKING AND DEGENERATIVE CHANGES ON MRI

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Purpose: The knee adduction moment (KAM) is an indicator of medial tibiofemoral loading during walking, and has been associated with the severity and progression of knee OA (osteoarthritis). While the KAM peak and impulse have been explored, the KAM loading rate has not yet been studied in relation to knee joint degenerative changes. This study aims to determine if there is a relationship between the KAM loading rate during walking and the severity of medial knee joint degenerative changes on MRI, and secondarily to compare the KAM loading rate to the KAM peak and impulse.

Methods: Research subjects were part of a study comparing knee loading in transfemoral amputees with age- and weight-matched non-amputee controls. All subjects underwent unilateral knee magnetic resonance imaging (MRI). The MRI scanning protocol and scoring of MRIs utilized the previously validated whole-organ magnetic resonance imaging score (WORMS) semiquantitative scoring methodology. Fourteen independent articular features were scored. The five features related to cartilage and bone characteristics were evaluated in 15 anatomical regions of the knee. Medial tibiofemoral joint sub-score was subsequently calculated. In addition, kinematic and kinetic data were collected while subjects walked at a controlled speed of 1.10 m/s (+/- 10%) in a motion analysis laboratory. Knee joint moments were calculated using a standard inverse dynamics approach, the magnitude of the peak KAM was identified, and the net positive impulse of the KAM was calculated. KAM loading rate was calculated as the maximum instantaneous value of the differentiated and smoothed KAM curve from gait initiation to the first KAM peak. Linear mixed effects regressions were carried out to assess the relationship between biomechanical loading variables and medial knee joint degeneration as represented by the medial tibiofemoral WORMS score. Additionally, the above models were carried out adjusting for weight or select KAM measures by adding these variables as independent covariates. Results are presented as slope of change in KAM per increase in WORMS score.

Results: Twenty-eight subjects (mean +/- SD age: 56.0 ± 8.7 years; weight: 83.3 ± 10.5 kg) were studied, including 14 amputees and 14 matched controls. Since there were no significant differences between amputee and control subjects in age, body weight, walking speed or biomechanical loading variables, all subjects were analyzed together. Subjects had a wide range of WORMS scores, with distribution of medial versus lateral tibiofemoral degeneration consistent with prior literature. Overall, there were statistically significant correlations between